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Origin of Heavy Metals amongst Nuisance Dust-Fall Particles in Western Iran

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ABSTRACT

The purpose of this study was to evaluated the origin of the heavy metals amongst nuisance dust particles in Sanandaj, Khorrmabad and Andimeshk cities located in different latitudes in western Iran for the dustiest year during last decade. Samples of dust-fall particles were collected with 10 days intervals from these three cities for the duration of June 2012 to July 2013 using Deposit Gauge Method. Concentration of the heavy metals including iron, manganese, zinc, copper, arsenic, chromium, silver, nickel, lead and cadmium were measured using atomic absorption spectroscopy. The Quantification of Contamination index (QC) was applied to evaluate the origin of heavy metals among dust-fall particles collected in three stations. The results revealed that the annual mean rate of dust-fall was 1.73, 2.66 and 3.37 g/m2 per 10 days for Sanandaj, Khorramabad and Andimeshk, respectively. The highest and the lowest amount of dust-fall were obtained for July and February, respectively, while Fe had the highest concentration among the metals studied. The temperature and wind speed were found to be the most correlated meteorological parameters to dust-fall content throughout the three stations. According to QC index; Ag, Cu, Cd, As, Pb, Mn and Zn (except Pb and Mn for Andimeshk) were derived mainly from similar origins such as anthropogenic activities but the increased values of Fe, Ni, and Cr were ascribed to natural processes. Furthermore, Cu had the highest correlation with other heavy metals measured and was determined the most stable metal amongst dust-fall particles for the three studied stations.

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INTRODUCTION

The dust-fall phenomenon is a regional and international environmental calamity (Garrison et al., 2003; Griffin and Kellogg, 2004) and is considered as one of the most important natural and atmospheric disasters (Prospero and Lamb, 2003). Dust storms are widely occurring in arid and semi-arid climates. Although this phenomenon is closely related to climatic conditions such as rainfall, temperature, wind, vegetation and soil type it generally occurs around northern and southern 30 degree latitudes more than other parts of the world (Griffin and Kellogg, 2004; Krueger et al., 2004; Ridgwell, 2003). Dust-fall particles globally change the natural cycles of meteorology, geology and the environment (Wang et al., 2005; Zhang et al., 2002). Besides, transportation of heavy metals within particulate matters threatens human health (Escudero et al., 2007; Khuzestani and Souri, 2013). Some of these metals contain the most serious environmental threats because of their toxicity and their ability to accumulate in biota. For example chromium, arsenic, silver, cadmium and lead have no positive physiological functions

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in the human body so they are considered as xenobiotic elements and every amount entrance of them into the body endanger human health (Hansson and Abedi-Valugerdi, 2003; Morais et al., 2012; Maleki et al., 2017; Tagliani et al., 2017). Ventura et al. (2017) studied concentration of heavy metals such as Cu, Cd, Pb, Cr, Mn, Ni, V, Zn, Na, K, Fe amongst air particulate matters (PMs) in Rio-de-Janeiro, Brazil, and showed that they were originated from industrial, traffic and natural sources. Feng et al. (2012) investigated Cr, Pb, Zn and Cu in particulate matters in Jinan of China and illustrated that all of the four studied metals have a significant accumulation in dust particles and their concentrations exceeded related baselines. Li et al. (2016) studied heavy metals of Cr, Ni, Pb, Cd, Cu, Mn, Co and Zn in a city of northern China and revealed that there was significant relation between lung cancer of the residents and concentration of Cr, Cd and Co in PMs. Khuzestani and Souri (2013) measured Fe, Mn, Cu and As in particles matters of Sanandaj city in western Iran. Their results showed that content of Cu and As demonstrated moderate contamination and minor to moderately severe enrichment. Soleimani et al. (2018) also studied concentration of Cd, Ni, Cu, As, Pb, Mn and Cr in seven locations of Esfahan city in central Iran and resulted that the concentration of Cu and Cr were higher than other studied metals. During last decade western Iran has experienced the heaviest dust-fall phenomenon in recent history (Rajabi and Souri. 2015; Rajabi and Souri. 2018; IRIMO, 2022). Objective of this study is to evaluate origin of the heavy metals of As, Pb, Cd, Ni, Ag, Cr, Cu, Zn, Mn and Fe amongst dust-fall particles throughout western half of Iran.

MATERIAL AND METHODS

Study area and sampling procedure

Three cities of Sanandaj (Station A), Khorramabad (Station B) and Andimeshk (Station C) located in different latitudes of western Iran were decided for dust-fall sampling (Figure 1). The dust-fall particulate samples collected according to the Deposit Gauge Method (Figure 2) (Jaradat et al. 2004; ASTM. 2010) in 10 days intervals for a period of one year with the most abundant dusty days during last decade from June 2012 to July 2013 were selected to evaluate origin of heavy metals amongst them (Figure 3).

Samples of each 10 days interval washed out into the collecting bottle within double-distilled water were kept in 105 °C degree until removal of all water containing. The amount of dust-fall

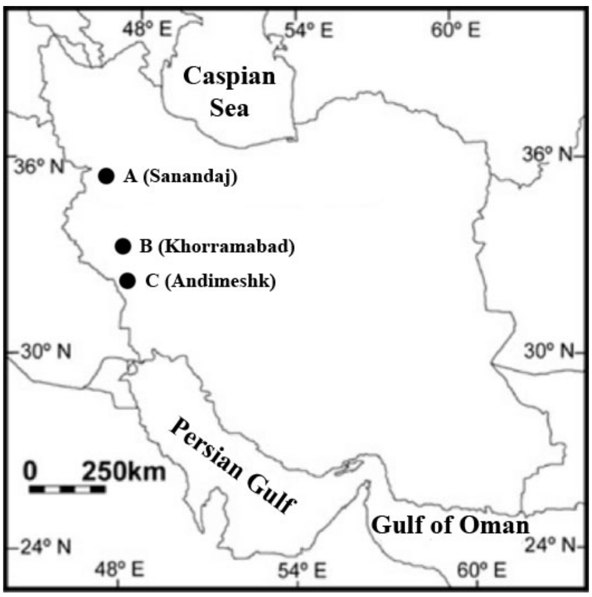

Fig. 1. Location of three sampling stations of A, B and C in different latitutes of western Iran

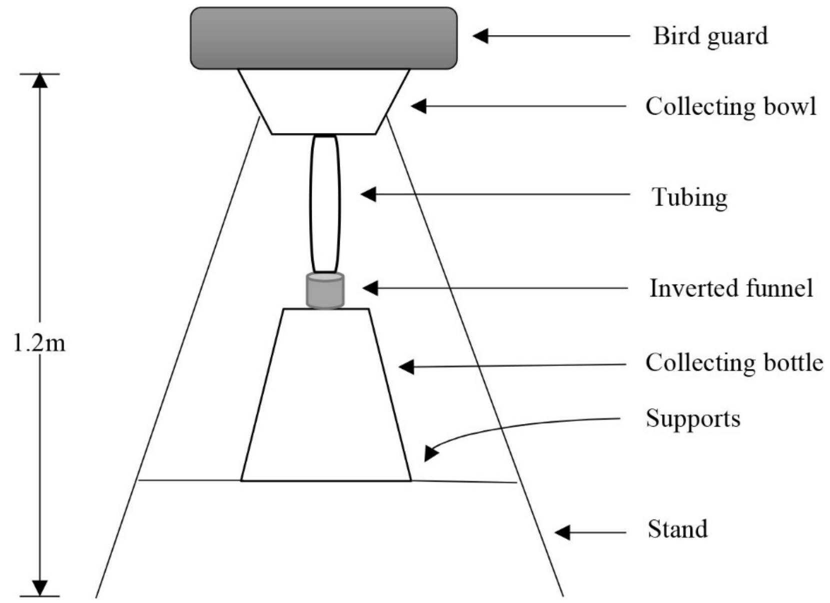

Fig. 2. Deposit Guage Method apparatus

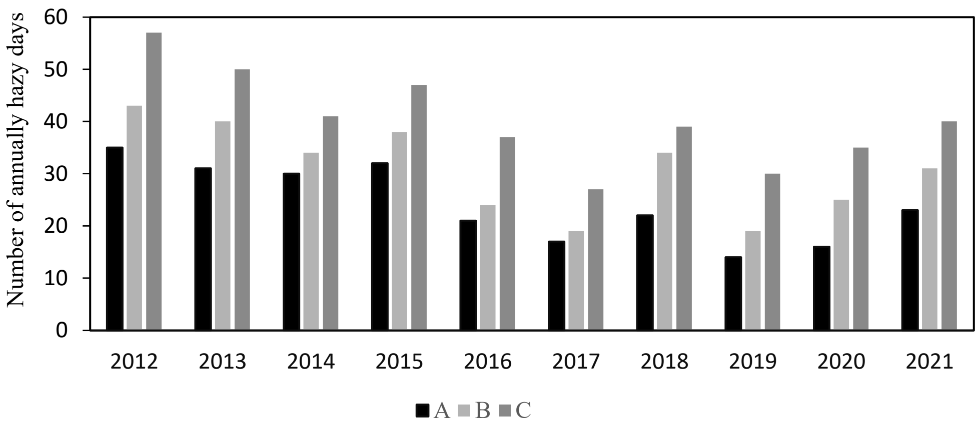

Fig. 3. Number of annually dusty days for the three stations of A (Sanandaj), B (Khorramabad) and C (Andimeshk) during the decade of 2012-2021 (www. Irimo.ir)

rate at each site for every 10 days interval was calculated using equation (1):

$$R = 1.273\ (W/D^2) \times (10/N) \times 10^4 \quad (1)$$

where R is dust-fall rate in g/m^2 per 10days; W is the total weight of dust fall washed out in the collecting container in g; D is the diameter of the dust collecting bowl in cm and N is the number of days of collection of samples (Jaradat et al., 2004; ASTM, 2010).

Analysis of samples

Measuring heavy metals of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), arsenic (As), chromium (Cr), silver (Ag), nickel (Ni), lead (Pb) and cadmium (Cd) was carried out through weighing 0.15 g of each dried sample adding 5mL concentrated nitric acid (HNO_3) with high purity into a 25mL test tube. The tube content was heated for 2hr at 95°C, sonicated for 30min using an ultrasonic bath at 50°C, and filtered throughout Whatmann No. 42 prewashed filter paper with 1% HNO_3. Then, the sample was diluted by 1% HNO_3 in a 25mL polyethylene volumetric flask (Jaradat et al., 2004; Khuzestani and Souri 2013). Finally, an atomic absorption spectrometer was applied to measure Fe and Mn by flame and Zn, Cu, As, Ag, Cr, Cd, Pb and Ni by furnace.

Quantification of Contamination index (QC)

The equation (2) was used to calculate Quantification of Contamination index (QC) which represent the anthropogenic concentration of an elements in the sample employing its background lithogenic concentration on earth crust (Asaah et al., 2006):

$$QC\ (\%) = (X - Xe/X) \times 100 \quad (2)$$

whereas QC is the index value in percentage, X is concentration of the heavy metal in the sample and Xe is average lithogenic concentration of the same heavy metal in earth crust as background (Zarei et al., 2014).

RESULTS AND DISCUSSION

Figure 4 shows seasonal dust-fall particles content throughout the three stations studied. The trend of changes of the dust-fall particles content had similar tendencies for the three stations with the lowest and the highest dust-fall quantity happened in winter and spring, respectively (Goudie el al., 2000; Léon and Legrand, 2003; Goudie and Middleton, 2006). Moreover, reducing trend of dust-fall content in south to north direction for western half of Iran (Andimeshk to Khorramabad and then to Sanandaj) for all seasons with distancing from the source of the dust-fall particles especially from territories in southern Iraq and northern Arabian Peninsula was revealed (Zhang et al., 2002).

Figure 5 shows seasonal average accumulated concentration of heavy metals amongst dust-fall particles on the three sampling stations. In Sanandaj station the highest average accumulated concentration of heavy metal was obtained for winter as simultaneously the lowest amount of dust-fall quantity happened for winter, too (Figure 4). Moreover, Sanandaj had more average accumulated concentration of heavy metals than Khorramabad and Andimeshk stations during fall, winter and spring seasons. Zhang et al. (2010) have cited that with increasing distance from the resource dust-fall particles tend to be smaller so they become are more capable of transporting heavy metals (Li et al., 2017). Smaller dust particles often contain more clay minerals with a high adsorption surface that have a high ability to transport heavy metals (Zarasvandi et al., 2010).

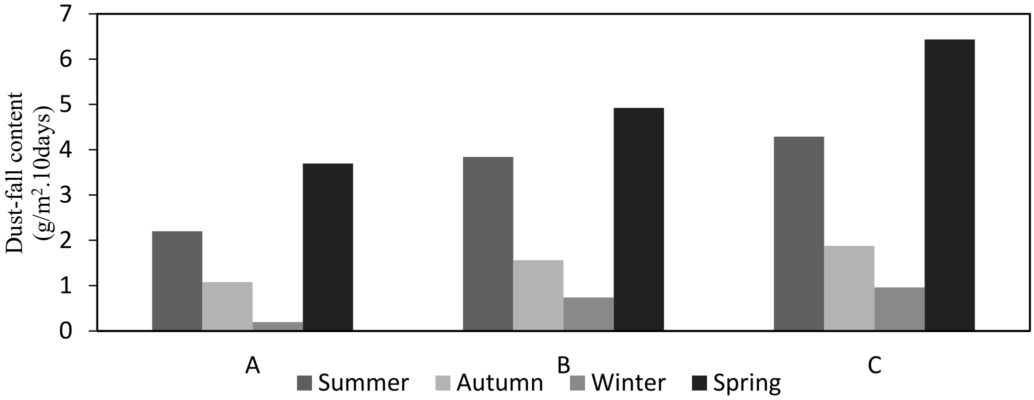

Fig. 4. Fluctuation of the dust-fall content at the three sampling stations of Sanandaj (Station A), Khorramabad (Station B) and Andimeshk (Station C) for the four seasons

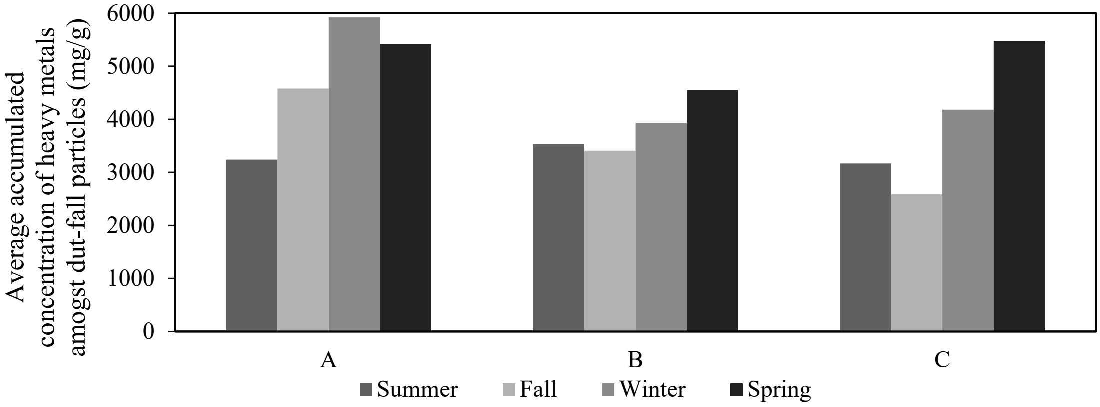

Fig. 5. Average accumulated concentrations of the heavy metals at the three sampling stations of Sanandaj (Station A), Khorramabad (Station B) and Andimeshk (Station C) for the four seasons

Table 1. Pearson's correlation coefficients for the relationships of seasonal dust-fall *content* to meteorological parameters of temperature, pressure, wind speed and humidity at the three sampling stations of Sanandaj (Station A), Khorramabad (Station B) and Andimeshk (Station C).

	site	Temperature	Pressure	Wind speed	Humidity
	A	0.254	0.325	0.235	-0.320
Summer	B	0.462*	0.224	0.351	0.087
	C	0.415*	0.135	0.384	0.255
	A	-0.763*	0.246	0.151	0.677*
Autumn	B	0.221	-0.058	0.342	-0.379
	C	-0.137	0.179	-0.048	-0.363
	A	0.750*	-0.358	0.550*	-0.569
Winter	B	0.842*	-0.442	0.656*	-0.460
	C	0.876**	-0.792*	0.725*	-0.753*
	A	0.421*	0.062	0.246	0.710*
Spring	B	0.604*	-0.320	0.494*	0.204
	C	0.570*	-0.456	0.750*	0.161

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Annual average concentration of dust-fall for Sanandaj, Khorramabad and Andimeshk measured were 1.73, 2.66 and 3.37 g/m^2.10 days, respectively, indicating that the mean dust-fall deposition rate decreases with increasing latitude (Menéndez et al., 2007; Hojati et al., 2012). In general, a heavy dust storm occurrence requires heating–dynamic systems with inclement conditions on ground surface (Nazari et al., 2016). In other words, the most of the dust storms occur during spring and summer but less frequently in autumn and winter (Shahsavani et al., 2011).

Table 1 shows the results of correlation coefficients using Pearson tests for the relationships of dust-fall content to the four effective meteorological parameters including temperature, pressure, wind speed and humidity. It appears that the dust-fall content is more correlated to air temperature and wind speed rather than air pressure and humidity. It means that increase of air temperature and wind speed make dust-fall phenomenon more probable (Masatoshi, 2002; Naddafi et al., 2006; Zhang et al., 2016).

Table 2. Pearson's correlation coefficients for the relationships of seasonal dust-fall content in Sanandaj (Station A), Khorramabad (Station B) and Andimeshk (Station C).

		Sanandaj	Khorramabad	Andimeshk
Summer	Sanandaj	1	0.846**	0.901**
	Khorramabad		1	0.987**
	Andimeshk			1
Autumn	Sanandaj	1	0.260	-0.166
	Khorramabad		1	-0.211
	Andimeshk			1
Winter	Sanandaj	1	0.398	0.334
	Khorramabad		1	0.621
	Andimeshk			1
Spring	Sanandaj	1	0.949**	0.954**
	Khorramabad		1	0.987**
	Andimeshk			1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 2 shows the correlation coefficients using Pearson tests for the seasonal correlation between dust-fall particles content in Sanandaj, Khorramabad, and Andimeshk. Despite the difference in the content of dust-fall in different seasons at the sampling stations (Fig.4) there is a significant relationship between the trend of dust-fall in spring and summer in all three stations which might be due to similar weather conditions in spring and summer throughout the three stations studied (Table 2).

Table 3 shows the maximum, minimum, mean, standard deviation, skewness and kurtosis for concentration of heavy metals amongst dust-fall particles in Sanandaj, Khorramabad, and Andimeshk. The order of mean concentration of heavy metals in sanandaj station: Fe> Mn> Cu> Zn> Ni> Pb> Cr> As> Ag= Cd, for Khorramabad and andimeshk stations: Fe> Mn> Cu> Zn> Ni> Pb> As> Cr> Cd>Ag. The comparison of heavy metal values shows absolute superiority of Fe content which corresponds to previous studies (Khuzestani & Souri., 2013; Mousavi et al., 2018; Krolak, 2000 and Jaradat et al., 2004). Moreover, the high concentration of Fe indicates the natural origin of the dust-fall phenomenon in the three stations (Khuzestani and Souri, 2013). Silver (Ag) also had the lowest concentration in the samples of dust-fall particles for three stations.

Heavy metals' concentrations amongst dust-fall samples of the current study are compared to other studies in Table 4. Ag and Cd had the two lowest average annual concentration in all three stations. Also, Fe, Mn, Cu and Zn had the four highest average annual concentration in three stations. Previous studies also reported Cd and Fe having the lowest and the highest average concentration of heavy metals amongst dust-fall particles, respectively (Mousavi et al., 2018).

As illustrated in Figure 6 the values of Quantification of Contamination index (QC) is used to describe the geogenic and anthropogenic origin of heavy metals contamination amongst dust-fall particles. The results revealed the negative values of QC for Fe, Cr, Ni throughout the three sampling sites a confirmation for geogenic origin of them while the positive values of QC emphasized on anthropogenic origin for Ag, Cu, Zn, Cd, As, and Pb (except Andimeshk) (Lin et al., 2005; Singh et al., 2002).

Values of the Pearson's correlation coefficients for the relationships between for Pb, As, Cd, Zn, Ni, Ag, Cr, Cu, Mn, and Fe contents amongst dust-fall particles of the three stations are depicted in Table 5. Positive significant correlations between various metals in this study could

Table 3. Maximum, minimum, mean, standard deviation, skewness and kurtosis concentration of heavy metals concentration amongst dust- fall particles at the three sampling stations of Sanandaj (Station A), Khorramabad (Station B) and Andimeshk (Station C) (mg/kg). Bold numbers represent the background values of the heavy metals in average shale, ppm (Hakanson, 1980).

site		Fe	Mn	Zn	Cu	As	Cr	Ag	Ni	Pb	Cd
		47200	**850**	**95**	**45**	**13**	**90**	**0.07**	**68**	**20**	**0.3**
A	Max	39960	1400	520	1300	32.00	32.00	1.90	115.50	75.08	1.90
	Min	5420	230	10	70	3.98	4.47	0.17	5.44	9.05	0.07
	Mean	19390	600	210	410	15.15	16.81	0.80	43.42	31.32	0.80
	Sd	8.10	0.28	0.14	0.37	6.69	8.18	0.47	28.18	19.11	12.33
	Skewness	0.42	0.92	0.42	1.03	0.53	0.15	0.78	1.00	0.96	2.80
	Kurtosis	-0.20	0.31	-0.73	0.43	-0.11	-1.40	-0.26	0.41	0.12	10.10
B	Max	28570	1000	400	360	24.30	23.33	0.76	91.15	58.28	1.98
	Min	6100	170	30	50	5.57	4.44	0.11	5.90	6.59	0.04
	Mean	14710	470	160	170	12.61	11.51	0.34	34.57	22.78	0.44
	Sd	5.77	0.21	0.10	0.07	4.13	5.14	0.15	24.04	16.56	9.50
	Skewness	0.78	0.72	0.57	0.92	0.50	0.91	0.79	0.96	1.48	2.10
	Kurtosis	-0.20	-0.18	-0.43	0.04	-0.09	-0.003	0.44	-0.19	3.22	4.31
C	Max	44340	1070	450	340	25.08	21.50	0.60	82.55	25.62	1.55
	Min	5710	150	10	90	3.27	5.30	0.13	4.68	5.00	0.05
	Mean	14800	400	170	180	11.68	10.07	0.29	33.81	14.61	0.33
	Sd	7.33	0.22	0.12	0.07	5.58	4.20	0.11	23.31	14.21	10.63
	Skewness	2.01	1.29	0.77	0.66	0.70	1.25	0.97	0.77	0.31	2.22
	Kurtosis	6.50	1.28	-0.40	-0.63	-0.06	0.85	0.98	-0.72	-0.93	4.27

Table 4. Heavy metals concentration amongst dust-fall samples of the three stations of the current study compared to some other regions (µg/g).

	Current study			**Khuzestani, and Souri, 2013**	**Soleimani et al., 2018**	**Królak, 2000**	**Jaradat et al., 2004**	**Momani et al., 2000**	**Tiwari et al., 2008**
	A	**B**	**C**						
As	15.15	12.61	11.68	18.28	32				
Pb	31.33	22.79	16.61		41	576.9	59.5	74	77
Cd	0.39	0.44	0.34		**7**	10.8	6.36	3/1	7/5
Ni	43.42	34.57	33.81		35	40			56
Ag	0.80	0.34	0.29						
Cr	16.81	11.51	10.07		70	29.9	65.5		131.6
Cu	410	170	180	61.3	49	521.6	91.9	94	43
Zn	210	160	170			4443.3	639.8	505	368
Mn	600	480	400	497.7	31	392.3			424
Fe	193900	147200	14800	14003.5		17702.8	13300		

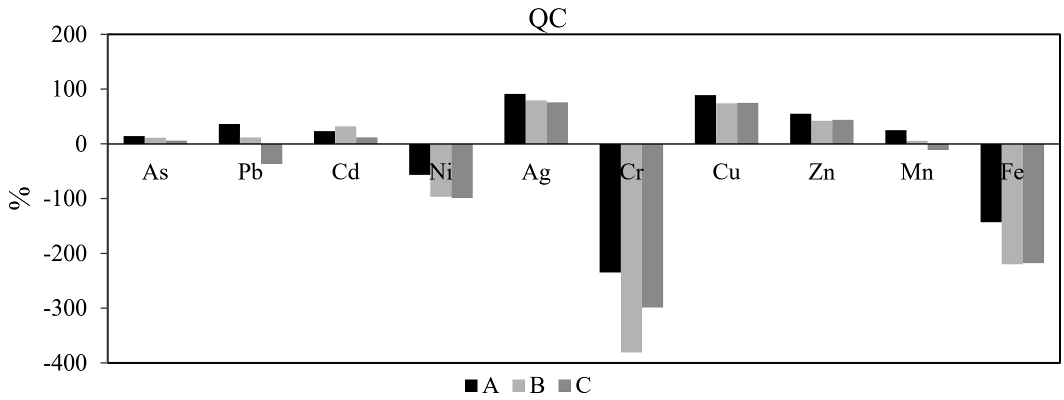

Fig. 6. QC values for heavy metals in dust-fall particles of study stations for the three sampling stations of Sanandaj (Station A), Khorramabad (Station B) and Andimeshk (Station C)

Table 5. Pearson's correlation coefficient matrix for the heavy metals content amongst the dust-fall particles throughout the three sampling stations of Sanandaj (Station A), Khorramabad (Station B) and Andimeshk (Station C).

	Fe	Mn	Cu	Zn	As	Pb	Cd	Ag	Cr	Ni
A										
Fe	1									
Mn	-0.185	1								
Cu	0.376*	0.555**	1							
Zn	0.141	0.693**	0.826**	1						
As	0.539**	0.342*	0.460**	0.362*	1					
Pb	0.321	0.545**	0.802**	0.744**	0.430**	1				
Cd	0.064	0.170	0.453**	0.264	0.128	0.220	1			
Ag	-0.011	0.716**	0.589**	0.583**	0.345*	0.602**	0.201	1		
Cr	0.025	0.743**	0.786**	0.843**	0.285	0.707**	0.272	0.650**	1	
Ni	-0.374*	0.362*	-0.017	0.157	0.107	0.076	-0.154	0.383*	0.145	1
B										
Fe	1									
Mn	0.018	1								
Cu	-0.181	0.387*	1							
Zn	-0.094	0.690**	0.652**	1						
As	0.469**	0.194	-0.042	-0.037	1					
Pb	-0.071	0.411*	0.485**	0.286	0.285	1				
Cd	-0.116	-0.233	-0.038	-0.025	-0.302	-0.037	1			
Ag	0.146	-0.035	0.136	-0.184	0.399*	0.439**	0.471**	1		
Cr	0.037	0.576**	0.621**	0.786**	-0.085	0.431*	-0.025	-0.099	1	
Ni	-0.112	0.481**	0.499**	0.674**	0.150	0.266	-0.291	0.002	0.482**	1
C										
Fe	1									
Mn	0.027	1								
Cu	-0.134	0.616**	1							
Zn	-0.133	0.647**	0.756**	1						
As	0.249	0.190	0.083	0.027	1					
Pb	0.318	0.448**	0.437**	0.407*	0.118	1				
Cd	-0.025	-0.258	-0.229	-0.206	-0.128	-0.237	1			
Ag	0.257	-0.015	0.146	-0.167	0.334*	0.270	-0.109	1		
Cr	0.95	0.520**	0.696**	0.664**	-0.061	0.382*	0.050	0.038	1	
Ni	-0.116	0.575**	0.430**	0.544**	-0.223	0.302	-0.380*	-0.028	0.349*	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

be evidence of similar origin for the heavy metals throughout the three stations studied (Ghrefat et al., 2011; (Soleimani et al., 2018).

Pearson's correlation analysis was employed to find the possible linear interrelationships between the various heavy metals content and physicochemical parameters (Badamasi et al., 2023). It is valuable since it can identify the correlations between variables that demonstrate the cohesiveness of data and define the influencing variables that assist in determining the sources of various heavy metals (Rakotondrabe et al., 2018; Ayub and Ahmad., 2020). The correlation coefficients between measured heavy metals in dust-fall particles has been previously applied to evaluate similarity/differentiation of heavy metals origin successfully (Lu et al., 2010; Taghipour et al., 2011). In current study; there was positive correlations of all metals measures to Cu (except Ni) and to Ag and Mn (except Fe and Cd) in Sanandaj station. Pearson test also showed positive correlations of Cu to Mn, Zn, Pb, Cr and Ni in Khorramabad and Andimeshk stations. Besides, there were positive significant correlations of Cr to Cu (Soleimani et al., 2018), of Mn to Zn, Cu, Ni and Pb and also of Pb to Cu and Mn in all the three stations (Mmolawa et al., 2011). This correlation between elements refer to probability of originating from the same source and/or similar geochemical behavior. The results of the present work showed that Cu, being most stable heavy metal in the dust-fall deposits which can be used as a reference element in calculations of enrichment coefficients of dust-fall regarding the heavy metals. According to Kabata-Pendias (2000) Mn or Al may also be applied as reference metals. Taking into consideration the high stability of Cu measurements and considering statistically significant correlations between the concentration and deposition of Cu and the other metals; Cu is recommendable to be applied as a reference element for western Iran (Krolak, 2000).

CONCLUSIONS

Fe had the highest and Ag had the lowest concentrations amongst dust-fall particles in western Iran. Furthermore, Cu was the most stable metal amongst the dust-fall particles throughout the three stations so it is recommendable to be used as a reference element for western Iran. Also, the highest and the lowest dust-fall levels were happened during spring and winter, respectively. Despite less dust-fall content in station A; the samples of this station had higher concentration of heavy metals. Moreover, temperature and wind speed were found to be the most correlated meteorological parameters to dust-fall content for the three sampling stations. Finally, evaluation of the heavy metals in dust-fall particles emphasized on geogenic origin of Fe, Cr, Ni but confirmed anthropogenic basis of Ag, Cu, Zn, Cd, As, and Pb.

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The present research did not receive any financially supported.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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